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# A NOVEL APPROACH FOR GRID INTERACTIVE PV SYSTEM USING FUZZY LOGIC BASED MPPT

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**Abstract -** *Photovoltaic (PV) cell characteristics are highly nonlinear that gives single Maximum Power Point (MPP) on P-V curve under uniform insolation condition. The characteristics and hence MPP point changes with the variation in insolation and temperature. In order to extract a maximum power from PV array, a fuzzy based MPP tracking algorithm is proposed.The algorithm accepts single input that is slope of P-V curve and generates the duty ratio as an output that operates the boost converter to track MPP. The algorithm gives faster convergence by applying variable step in duty ratio and gives accurate MPP. The two stage grid interactive PV system described in this project supplies active power as well as provides harmonic and reactive power compensation. This additional feature increases the effective utilization of PV inverter and increases the overall efficiency of the system.The simulation results validate the performance and stability of the grid interactive PV system using the proposed algorithm for active current Injection as well as harmonics and reactive power compensation. ( Size 10 & Italic , cambria font)*

***Key Words***: **power quality (PQ), renewable energy, Photo Voltaic (PV) System**

## 1.INTRODUCTION *( Size 11 , cambria font)*

FACTS devices are capable of mitigating the power quality problems.. On the other hand, the ever-increasing number of power-electronics-driven loads used usually in the industry has brought about unusual power quality problems. In division, power-electronics-driven loads generally need ideal sinusoidal supply voltage in order to function appropriately, whereas they are the most responsible ones for uncharacteristic harmonic currents level in the distribution system

Photovoltaic(PV) amongst the renewable energy sources has gained popularity as it is clean and safe, zero fuel cost, negligible maintenance and running cost, zero noise and air pollution

One of the challenges in using PV system is extracting maximum power that varies with the change in solar insolation and temperature. To increase the efficiency of the PV system, it is required to operate at the maximum power point (MPP). Several methods are presented for maximum power point tracking (MPPT) from PV array [1-2] like Perturb and Observe [1] (P&O), incremental conductance, open circuit voltage, short circuit current, ripple based, fuzzy based, β-method etc. The P&O technique is simple to implement but gives oscillations around final operating point and may fail under rapidly changing environmental conditions [1]. The incremental conductance technique gives good performance under rapidly changing environment conditions but has complexity in implementation [1-2]. The constant voltage and constant current techniques are simple but they do not track the MPP accurately [1-2]. The β-method gives good performance and higher tracking efficiency but has complex calculations and depends on accurate β-factor [2].

Fuzzy logic is becoming popular for MPP tracking which overcomes the disadvantages of conventional methods. The MPPT control using fuzzy

logic is simple to implement, gives better convergence speed, and improves the tracking performance with minimum oscillation. Many stand alone PV system and two-stage grid connected PV system use fuzzy logic controller for MPP that takes at least two input and generates the control output [3-5]. The fuzzy logic MPPT used in [6] controls the duty ratio of the DC -DC converter in stand-alone system using change in slope of P-V curve as input and change in voltage as output. The authors in [7] proposed fuzzy logic controlled modified Hill Climbing method for MPP tracking in microgrid stand-alone PV system. The algorithm generates

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change in duty ratio as an output with change in power and change in current as input.

In this paper, an MPPT based on simple fuzzy logic control strategy is proposed for two-stage grid interactive PV system. The proposed fuzzy logic MPPT controller accepts single input that is slope of P-V curve (dp/dv) and generates the duty cycle for the boost converter as an output to operate the PV array at MPP and gives the maximum PV power to be injected in the grid. The proposed technique gives faster convergence with less complexity. The validity and robustness of the proposed algorithm is demonstrated through simulation results.

Due to high cost of PV panels, the effective utilization of PV system is essential. In order to utilize the PV system effectively, authors in [8-10] proposed grid connected PV system with active and reactive power control. In [8], a multi function two stage grid connected PV system with VAR compensation is proposed. The control system uses synchronous frame PI controllers and a two stage configuration with a dc boost converter for MPPT and the inverter for synchronization with grid. The control algorithm proposed in [8] is only usable with linear loads. In line with this and considering the power quality problem caused by growing number of nonlinear loads, the author in [11] has proposed grid interconnection of renewable energy sources with power quality improvement feature using 4-leg inverter.

The reference currents are generated based on unit sinusoidal template generated using PLL and dc link voltage control loop. Hence, the accuracy depends on the PLL and proper tuning of PI controller. Also, single-stage system imposes the problem of maintaining dc link voltage under lower insolation condition. Based on work in [11], single-stage grid connected photovoltaic interface with VAR compensation and active filtering functions is presented in [12].

The two stage grid interactive PV system described in this paper supplies active and reactive power as well as provides the harmonic compensation during day time. At night, the PV inverter still provides harmonic and reactive power compensation. Thus, the overall utilization of PV system is increased. The simulation results obtained using proposed algorithm gives the validity of the grid interactive PV system for reactive power and harmonic compensation features in addition to active power injection.

## 2. PV ARRAY MODELLING AND CHARACTERISTICS

The PV array is made up of number of PV modules connected in series called string and number of such strings connected in parallel to achieve desired voltage and current. The PV module used for simulation study consists of 36 series connected polycrystalline cells.

### 2. 1 PV Model

The electrical equivalent circuit model of PV cell consists of a current source in parallel with a diode [14] as shown in Fig 4.1

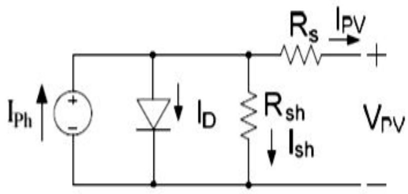



Fig -1 Electrical Equivalent Circuit Model of PV Cell

From the electrical equivalent circuit of the PV cell, PVoutput current (IPV) is given by

$$I_{pv} = I_{ph} - I_D - I_{sh} \quad (1)$$

Where,

$$I_D = I_o\left(\frac{e^{q(V_{pv}+I_{pv}R_s)}}{\eta kT}\right) \quad (2)$$

$$I_{sh} = \frac{V_{pv}+I_{pv}R_s}{\eta R_{sh}} \quad (3)$$

The parameters q, η, k and T denote the electronic charge,ideality factor of the diode, Boltzmann constant andtemperature in Kelvin respectively. Iph is photocurrent, I0 isdiode reverse saturation current, IPV and VPV are the PV outputcurrent and voltage respectively.

As the value of Rsh is very large, it has a negligible effecton the I-V characteristics of PV cell or array. Thus (1) can besimplified to

$$I_{pv} = I_{ph} - I_o\left(e^{\frac{q(V_{pv}+I_{pv}R_s)}{\eta kT}}-1\right) \quad (4)$$

For PV array consisting of Ns series and Np parallel connectedPV modules, (4) becomes

$$I_{pv} = N_p\left\{I_{ph} - I_o\left(e^{q\frac{(V_{pv}+I_{pv}R_s)}{\eta kTNs}} - 1\right)\right\} \quad (5)$$

### 2.2 PV Characteristics

The PV model is simulated using Solarex MSX60, 60W PV module. The simulated I-V and P-V characteristics of the Solarex PV module at constant temperature and varying insolation are shown in Fig.2(a) and Fig 2(b) respectively. It can be seen from Fig 2(a) that the decrease in insolation reduces the current largely but voltage fall is small. Fig 2(b) shows that the reduction in insolation reduces the power largely as both voltage and current are decreasing.

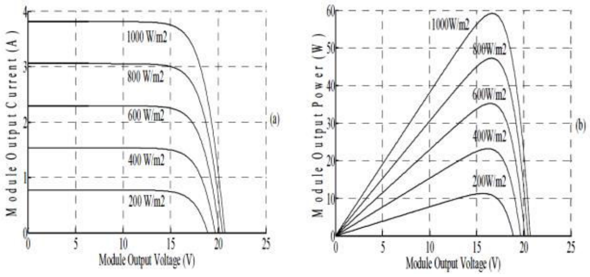



Fig- 2 (a) I-V characteristics and (b) P-V characteristics of the
Solarex PV module at constant temperature T=30$^0$C and varying insolation.

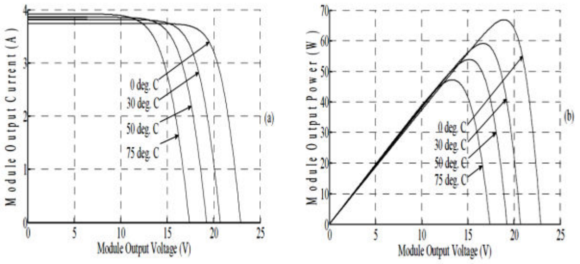



Fig -3 a ) I-V characteristics and (b) P-V characteristic Solarexmodule at constant insolation λ =1000W/m2 and different temperature.

**2.3 MPPT ALGORITHM**

From the simulated I- V and P-V characteristics of the PV module, it can be seen that the characteristics are highly nonlinear. Also, there is single point on P-V curve where the PV can produce maximum power. The MPP changes with change in insolation and temperature. Therefore, an MPPT controller is required to extract maximum available power from the PV array under varying load and changing environmental conditions. This paper proposes a novel fuzzy logic based MPPT controller.

Fuzzy logic can model or control non-linear systems that are difficult to model mathematically. The fuzzy logic is chosen for MPPT as it gives appropriate performance for varying dynamics, higher convergence speed, robust and simple to design compared to conventional methods. The major objective of the proposed controller is to track and extract maximum power from the PV arrays for a varying solar insolation and cell temperature. The block diagram of the proposed fuzzy logic controller (FLC) is shown in Fig. 4. The major functional blocks of the FLC are described as follows.

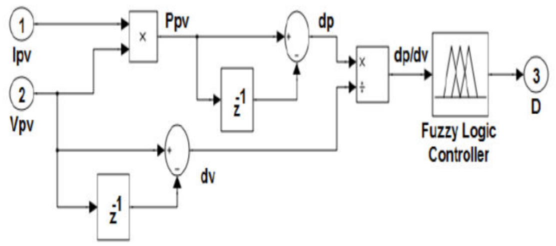



Fig -4 Block diagram of proposed fuzzy based MPPT controller

**2.4 Fuzzy rule base**

The fuzzy rules should be precisely defined based on the knowledge in order to generate an output duty ratio as per the magnitude of the slope of P-V curve to operate the PV array at MPP. When the slope of P-V curve is positive then to reach towards MPP, the duty ratio of boost converter is decreased in order to increase the PV operating voltage. Similarly, if the slope of P-V curve is negative then to move the operating point at MPP, the duty ratio is increased. The seven rules used for tracking the MPP in the proposed technique are listed in Table4.

**Table 1 Fuzzy Rules**

| $\frac{\Delta P}{\Delta V}$ | NB | NM | NS | ZO | NB | NM | NS |
|---|---|---|---|---|---|---|---|
| D | PB | PM | PS | ZO | PB | PM | PS |

The proposed fuzzy logic MPPT controller applies variable steps in duty ratio for controlling the boost converter as per the current operating point and hence, gives faster convergence to MPP compared to conventional algorithms. The proposed algorithm gives robust performance under rapidly changing environmental conditions under which the conventional P&O technique is likely to fail [1]

**2.5 CONTROL OF GRID INTERACTIVE PV SYSTEM**

The grid interactive PV system configuration used forsimulation study is shown in Fig 5. It consists of two powerprocessing stages: DC-DC boost converter as first stage andthree-phase voltage source inverter as second stage. The boostconverter stage provides not only the boosting of PV outputvoltage for grid connectivity but also used as MPP tracker.

By controlling the duty ratio of boost converter using theproposed fuzzy based MPPT controller,the current corresponding to maximum power is injectedinto the grid. The second inverter stage is used for multiplefunctions: active power injection, harmonic compensation of non linear load connected with the grid,Reactive power compensation of the load. The additional functionality of the PV inverter as a shunt active power filter increases the overall efficiency of the system. The inverter switching signals are generated using the current control technique based on hysteresis current controller.

**2.5.1 Reference Current Generation**

The reference current generator block generates thereference current to be injected into the grid upon sensing thevoltage at the Point of Common Coupling (VPCC) and loadcurrents using instantaneous active and reactive power (p-q)theory [17]. For the computation of p and q, the three phasevoltages at the point of common coupling (PCC) and loadcurrents must first be transformed to the stationary two axis(α-β) co-ordinates. The instantaneous real and reactive powerp and q are determined using equations (9)-(13).

$$V_{\alpha\beta} = C \times V_{abc} (9)$$

$$I_{\alpha\beta} = C \times I_{Labc} (10)$$

$$\text{Where, } C = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} (11)$$

$$P = v_\alpha \times I_\alpha + v_\beta \times I_\beta \quad (12)$$

$$q = V_\alpha \times I_\beta - V_\beta \times I_\beta (13)$$

Both instantaneous power quantities p and q consists of dc andac components. While the dc components p~ and q~, arise due tothe fundamental, the ac components p~ and q~ are a result of harmonic components. In order to inject active power generated by PV obtained using the proposed MPPT controller and also to provide harmonic as well as reactive power compesation as per the load demand , the reference for active and reactive power are generated according to (14) and (15).

$$p^* = P_{pv} + \tilde{p} (14)$$

$$q^* = q = \bar{q} + \tilde{q} (15)$$

The ac component p~ is determined by first extracting p~,using a very low cut off low pass filter and then subtracting itfrom p obtained using (12). Finally, the reference currents aregenerated as per (16) and (17).

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \begin{bmatrix} v_{s\alpha} v_{s\beta} \\ -v_{s\beta} v_{s\alpha} \end{bmatrix}^{-1} \begin{bmatrix} p^* \\ q^* \end{bmatrix} (16)$$

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = [C]^T \begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} \qquad (17)$$

**2.5.2 Hysteresis Current Controller**

The hysteresis current controller compares the three phasereference currents (ica*, icb*, icc*) generated using (17) with theactual inverter currents (ica, icb, icc) and generates the switchingpulses as per the logic given below:

if ( ica>ica* + hb )

leg-a upper switch is OFF and lower switch is ON

if ( ica<ica* - hb )

leg-a upper switch is ON and lower switch is OFF

where, hb is the hysteresis band around the reference currentwhich is usually 5 % of the maximum current to be injected bythe inverter. Similarly, control also for leg-b and leg-c of the inverter switches are generated.

**3. .SIMULATION RESULTS**

The simulation of grid interactive PV system shown in Fig 5 is performed using Matlab/Simulink.

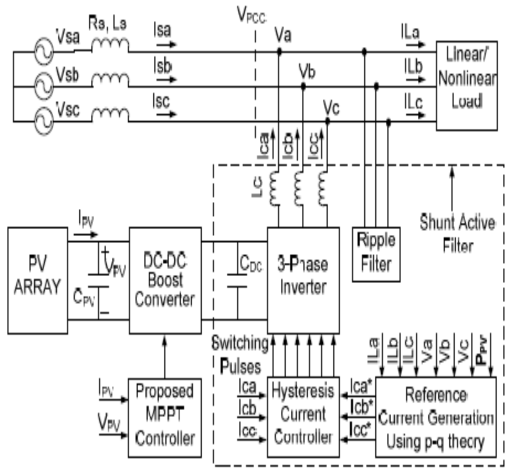



Fig -5 Grid connected PV system configuration

In simulation, the performance of proposed algorithm for extracting maximum power from the PV array is analyzed under varying insolation and load conditions. The additional feature of harmonic and reactive power compensation for different load and insolation is also studied.

**3.1 PV Characteristics**

The PV model is simulated I-V and P-V characteristics of the PV module at constant temperature and varying insolation are shown in Fig6 and Fig7 respectively. It can be seen from Fig6 that the decrease in insolation reduces the current largely but voltage fall is small. Fig 7 shows that the reduction in insolation reduces the power largely as both voltage and current are decreasing.

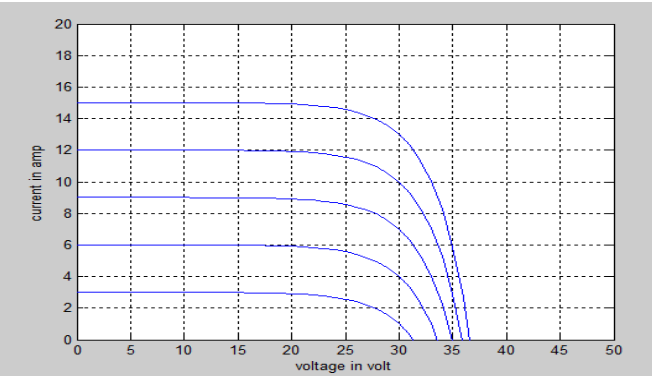



**Fig-6** I-V characteristics

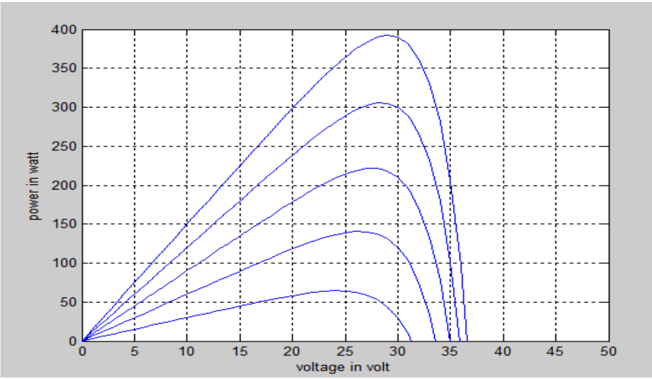



**Fig-7.** P-V characteristics of the PV module at constant temperature T=25$^0$C and varying insolation

### 3.1.1 Performance of the system with constant insolation and combination of linear and nonlinear load.

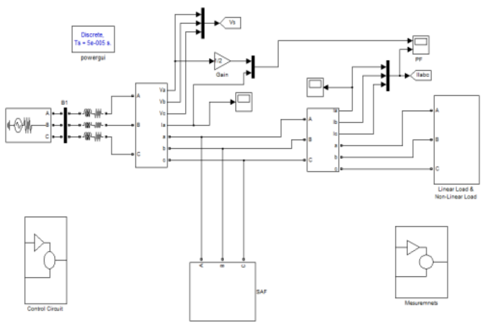


Fig-8 The system with constant insolation and combination of linear and nonlinear load.

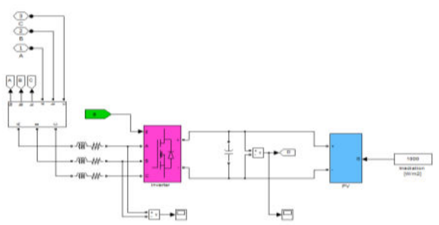


Fig-9 Performance of shunt active power filter with constant in 1000 (W/m2) insolation

Fig 10 shows the performance of the PV system for active power injection as well as harmonic and reactive power compensation for combination of linear and nonlinear load with constant insolation of 1000 W/m2. It can be seen from Fig 10 that the current drawn from the grid is sinusoidal and in phase with the grid voltage as shown in Fig10. This verifies the harmonic and reactive power compensation with active current injection

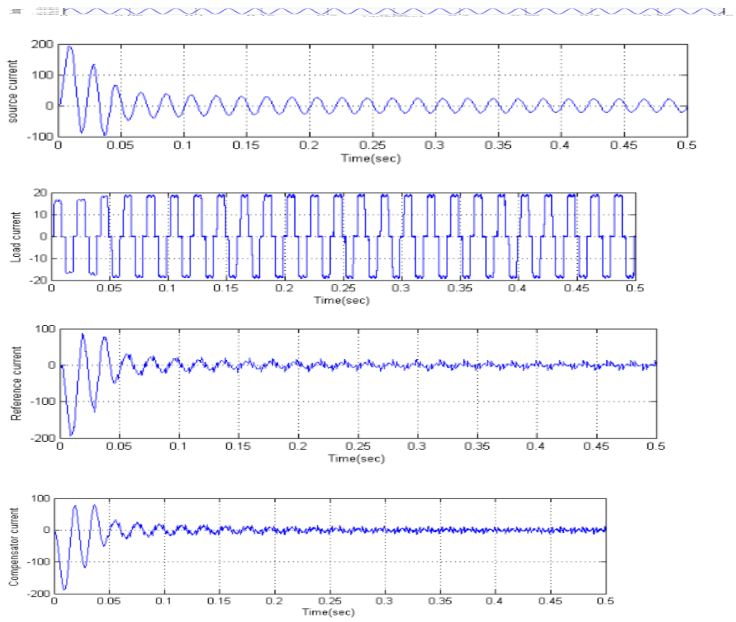



Fig 10 Performance with constant insolation and combination of linear and nonlinear load: (i) Voltage at the PCC (ii) Source current after compensation (iii) Load current (iv) Reference current (v) Compensator current (vi) DC bus voltage

The total harmonic distortion (THD) of load current is 21.14% as seen in Fig.11(a) and after compensation the source current THD is reduced to 4.72% seen from Fig. 11(b).

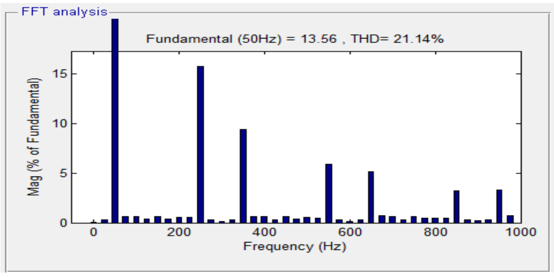



Fig-11 Magnitude spectrum of source current (a) before compensation

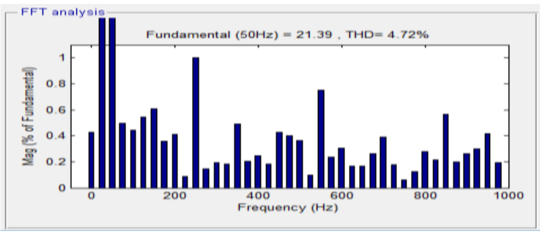



Fig-11 Magnitude spectrum of source current (b) after compensation

**3.1.1 B. Performance with constant insolation and nonlinear**

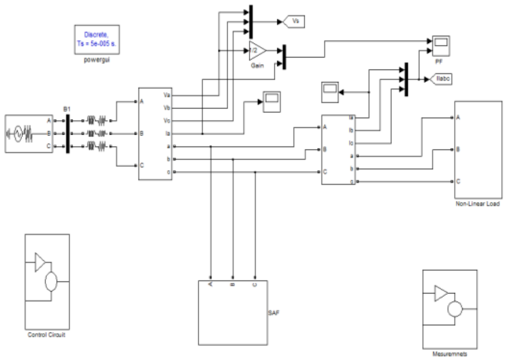


Fig-12 The system with constant insolation and nonlinear load.

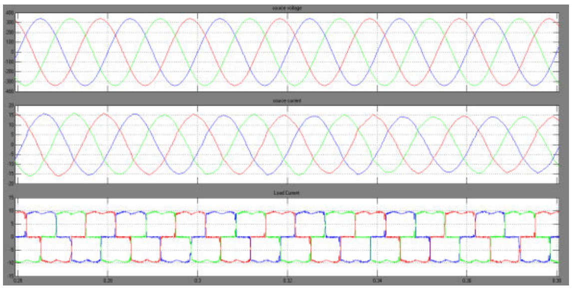


Fig-13 Performance with nonlinear load SourceVoltage,Source current andLoad current in three phase

Fig 13 shows the harmonic compensation of nonlinear load with constant insolation of 1000 W/m2. It can be seen from Fig 13 that the grid current is in phase with the grid voltage. The THD of load current is 28.05% as shown in Fig. 13 that is reduced to 5.17% in the source current after compensation as seen from Fig. 13

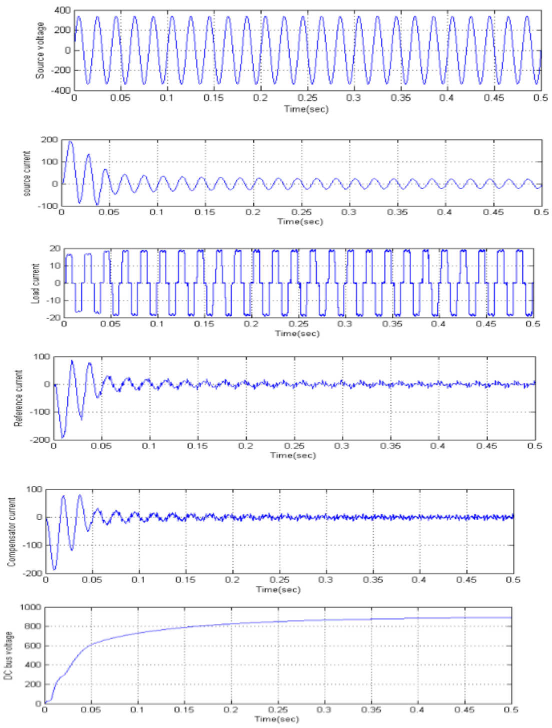


Figure 13 Performance with constant insolation and nonlinear load: (i) Voltage at the PCC (ii) Source current after compensation (iii) Load current (iv) Reference current (v) Compensator current (vi) DC bus voltage

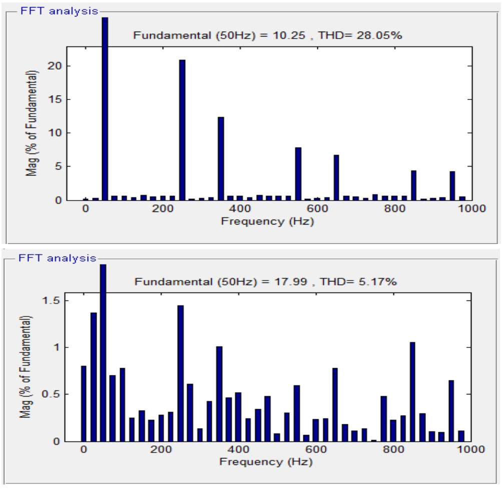



Fig 14 Magnitude spectrum of source current (a) before compensation and (b) after compensation

**C. Performance with change in insolation and with nonlinear**

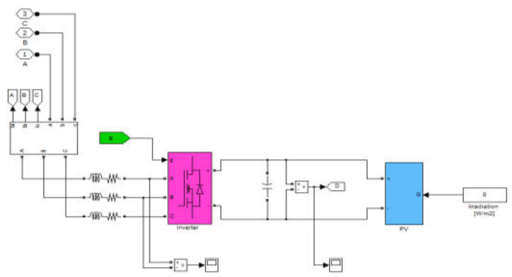
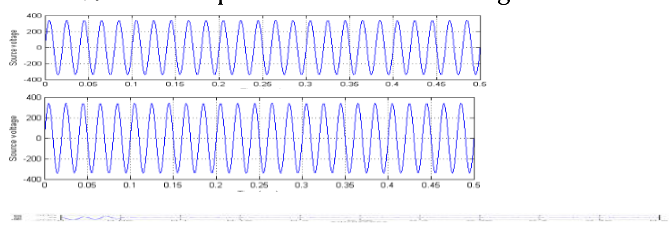


Fig 15 Performance of shunt active power filterwith change in 0 (W/m2) insolation

In this part, the performance of the system is analyzed for the shunt active power filter in the absence of sun. With non-linear load connected with the system, the insolation is zero. Fig 16 The PV system still supplies the harmonic and reactive components ofthe non-linear load. This ensures the effective utilization of the PV inverter at night. It can be noticed that the system responds quickly (within two grid cycles) and its performance is fairly good under varying insolation condition. The THD of source current is 28.78% as shown in Fig 16 before compensation that is reduced to 5.73% after compensation as shown in Fig 17



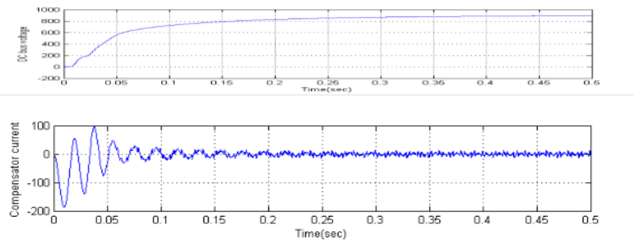



Fig 16 Performance under 0 insolation and nonlinear load: (i) Voltage at the PCC (ii) Source current after compensation (iii) Load current (iv) Reference current (v) Compensator current (vi) DC bus voltage

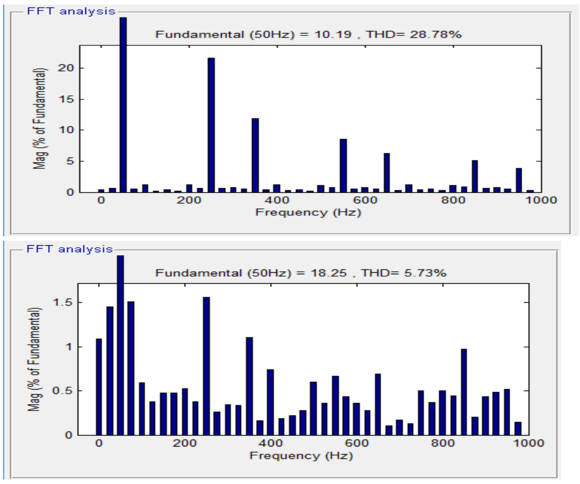



Fig 17 Magnitude spectrum of source current (a) before compensation and (b) after compensation

Thus, from the simulation results, it is verified that the proposed grid interactive PV system provides the control of active and reactive power as well as harmonic compensation using novel MPPT algorithm under most of the situations of insolation and load variation. It can be remarkably noticed from Fig12, Fig13 and Fig14 that the proposed fuzzy logic based MPPT controller maintains the DC Bus Voltage well regulated under varying insolation and load conditions while tracking the MPP.

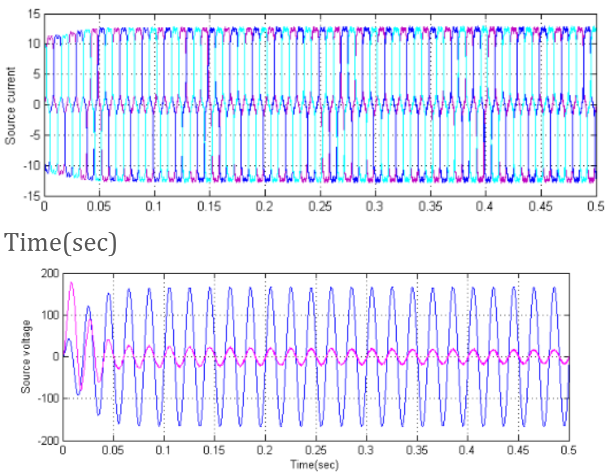



Fig -18 Source Voltage, Source Current at ph-A and Load Currents at threephase of nonlinear load.

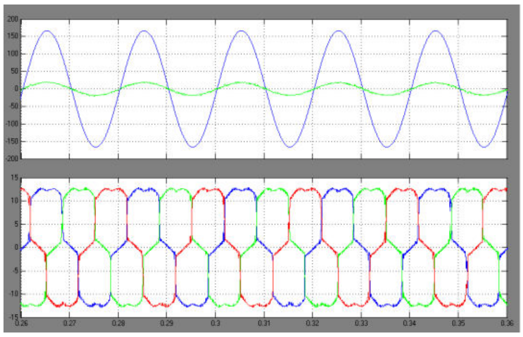


Fig-19 Voltage, Source Current at ph-A and Load Currents at threephase of linear and nonlinear load.

## 4 CONCLUSION

In this project, multi functional grid interactive PV system is presented using a novel fuzzy logic based MPPT. The proposed MPPT controller is able to track the MPP accurately under uniformly varying as well as rapidly changing insolation and gives faster convergence as a variable step size in duty ratio is applied inherently by the algorithm.

The proposed fuzzy controller maintains the dc link voltage within the limit for injecting the power into the grid. Apart from injecting active power during day time, the PV inverter also compensates the harmonics and reactive power during day time as well as at night. The current drawn from the grid is sinusoidal and the total harmonic distortion is well below the specified limit in the IEEE-519 standard.

The simulation results validate the performance of grid interactive PV systemfor both active power injection as well as shunt active power filter functionality to mitigate the power quality issues thus increases the utilization factor of the system.

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